haemoglobin, an increase in weight, and a decline in the values for the serum sodium, although the mean corpuscular haemoglobin remained unaltered.

We thank Dr. A. D. Leigh for permission to publish these results and Dr. D. R. C. Willcox, clinical pathologist, who supervised the laboratory investigations. We also thank Mr. A. E. Maxwell, statistician, for checking the statistical data.

REFERENCES

- Bain, C. W. C., Ashton, F., and Jones, B. P. (1955). *British Medical Journal*, 1, 817.
 Doyle, A. E., McQueen, E. G., and Smirk, F. H. (1955). *Circulation*, 11, 170.
 Foote, E. S. (1955). *British Medical Journal*, 1, 1192.
 Gamble, J. L. (1947). *Extracellular Fluid*, p. 1. Cambridge, Mass.
 Gaunt, R., Renzi, A. A., Antonchak, N., Miller, G. J., and Gilman, M. (1954). *Ann. N.Y. Acad. Sci.*, 59, 22.
 Locket, S. (1955). *British Medical Journal*, 1, 809.
 McNeill, D. L. M. (1955). *Ibid.*, 1, 1339.
 Moore, J. N. P., and Martin, E. A. (1955). *Lancet*, 1, 1126.
 Persson, I. (1951). *Nord. Med.*, 46, 1564.
 Rønnow-Jessen, V. (1955). *Lancet*, 1, 122.
 Smirk, F. H., Doyle, A. E., and McQueen, E. G. (1954). *Ibid.*, 2, 159.
 — and McQueen, E. G. (1955). *Ibid.*, 2, 115.
 Wallace, D. C. (1955). *Ibid.*, 2, 116.
 Wilkins, R. W. (1954). *Ann. N.Y. Acad. Sci.*, 59, 36.

REASSESSMENT OF VALUE OF OXYGEN MASKS THAT PERMIT REBREATHING

BY

J. E. COTES, B.M., M.R.C.P.

With the technical assistance of A. J. MERRICK

(From the Pneumoconiosis Research Unit of the Medical Research Council, Llandough Hospital, Penarth, Glamorganshire)

The therapeutic value of oxygen inhalation is well established, and it may be given safely with immediate benefit to the patient in a number of conditions. In patients with carbon dioxide retention due to chronic disease of the chest, however, oxygen therapy may accentuate the retention by depressing ventilation (Donald, 1949; Richards, 1950) and lead to coma. This danger is reduced when oxygen is given intermittently or in small amounts (Barach, 1948). Carbon dioxide retention may occur even when equipment with minimal deadspace is used for oxygen administration (Prime and Westlake, 1954). The oxygen mask itself may aggravate this tendency by permitting the re-breathing of exhaled air from the oxygen reservoir bag.

The present investigation into the effect of rebreathing was provoked by the observation that some dyspnoeic patients for whom oxygen therapy seemed desirable were unable to tolerate a mask operating on the re-breathing principle, whereas they did benefit from the same flow of oxygen given by a mask of the Haldane type.

Historical

The oxygen reservoir bag was introduced by Haldane in 1917 to prevent wastage of oxygen during expiration. Exhalation into the bag was prevented by a non-return valve in its neck. When wearing the Haldane mask (Fig. 1) the subject inspires first all the oxygen in the reservoir bag and then air through a hole in the facepiece. The expired gas passes out through this hole.

The rise in alveolar oxygen concentration of normal subjects, using this and other types of oxygen equipment, is shown in Fig. 2, using published data (Davies and Gilchrist, 1925; Hilton, 1928; Poulton and Adams, 1936; Christie, 1938; Card *et al.*, 1940; Christensen *et al.*, 1946; Burns and Hall, 1953). The Haldane mask, with an oxygen

flow of only 2 to 3 litres a minute, has been found to restore to normal the arterial oxygen saturation in desaturated subjects (Meakins, 1920, 1921). The mask proved less efficient when used with high oxygen flows calculated to raise to a maximum the alveolar oxygen tension (Davies and Gilchrist, 1925); some air was inevitably inspired through the hole in the facepiece, and alveolar oxygen concentrations of more than 60% were seldom attained (Fig. 2, Haldane mask A). An expiratory valve in place of the air-mix aperture overcame this difficulty, and the Haldane mask then became effective at all oxygen flows (Fig. 2, Davies-Gilchrist mask). The mask was not widely used, however, as it was expensive, heavy, uncomfortable, and difficult to sterilize and maintain (Campbell and Poulton, 1935).

The Boothby, Lovelace, and Bulbulian (B.L.B.) mask, introduced in 1938, overcame a number of these limitations. This mask was essentially an improved light-weight version of the Haldane mask, with a more comfortable and better-fitting facepiece, but it differed in having a smaller reservoir

FIG. 1.—Haldane mask.

FIG. 2.—Alveolar oxygen concentrations in normal subjects wearing different types of personal oxygen equipment.

bag and no valve between the bag and facepiece. The effectiveness of this design was claimed to be due both to the rebreathing of oxygen-enriched expired air and to some increase in ventilation on account of the carbon dioxide accumulation (Boothby, Lovelace, and Uihlein, 1940). However, since the oxygen is mainly inspired at the beginning of inspiration, and the gas conserved and used again is that expired at the beginning of expiration, no useful economy over the Haldane type is to be expected. Carbon dioxide accumulation in the bag occurs, especially at high respiratory frequencies, but Boothby and his colleagues have claimed that the inspired carbon dioxide is less than 1% in the total inspire; the estimate has, however, been disputed (Barach, 1940). Other factors which affect efficiency equally in the B.L.B. and Haldane masks are the flow characteristics of the orifices and tubes, and the rigidity of the bag. When these are similar the efficiency of both masks is the same (Card *et al.*, 1940; B.L.B. and Haldane B, Fig. 2). However, all these studies have been made on normal subjects.

Method

The ventilation has been measured at rest over two 20-minute periods in 20 subjects (6 normal men and 14 patients with chronic respiratory failure) breathing 3 litres of oxygen a minute through a mouthpiece modified alternatively to have the volume and flow characteristics either of the B.L.B. or of the Haldane mask. The average ventilation values over the last ten minutes of each period have been used for analysis. In eight normal subjects measurements were also made during the fifth to tenth minutes of stepping exercise at 200 kg.m./min. The total ventilation, which is the sum of the ventilations through the air-mix aperture and the oxygen reservoir bag, was obtained using the apparatus shown (Fig. 3).

The two gas-meters agreed to within 1% of each other and of a Tissot spirometer. The combined air-flow resistance of the gas-meters and valves, at the peak flows anticipated under the conditions of the experiments, was approximately 30% of that of the air-mix aperture. A change in resistance of this order was found to be insufficient to affect the ventilation materially.

The assembly, as illustrated, operated on the B.L.B. principle, and conversion to the Haldane principle was made by inserting a non-return valve into the neck of the reservoir bag. In this form (dead-space 55 ml.) the difference between

FIG. 3.—Apparatus used for the measurement of respiration minute-volume.

the oxygen flow into the bag (3 l./min.) and the minute-volume recorded on gas-meter 1 (which in the normal subjects averaged 0.9 l./min. ambient) was that volume of oxygen which flowed into the reservoir bag and on into the lungs during inspiration; this was added to volumes recorded on the meters to obtain the total ventilation.

The carbon dioxide concentration of the gas in the re-breathing bag was analysed in seven cases, using an infra-red gas analyser, sampling continuously at 100 ml. per minute; 50-ml. samples of the gas in the bag at the end of expiration were also analysed.

In the same experiments the pressure fluctuations in the mouthpiece were registered by a capacitance manometer and pen recorder with a frequency response of 1/80 second, connected to the mouthpiece by an air-filled tube.

Results

Normal Subjects.—The mean resting ventilation in six normal subjects, using the apparatus on the Haldane principle, was 7.5 l./min. B.T.P.S. (range 5.6–10.2). The ventilation was on average 52% higher when re-breathing was permitted by the removal of the valve (mean 11.4, range 8.1–12.7 l./min.). The mean increase was 3.9 (range 2.3–6.4) l./min. The mean ventilation at 200 kg.m./min. without re-breathing in eight other normal subjects was 21.8 (range 18.6–26.4) l./min. at the same oxygen flow. With re-breathing it was 25.5 (range 21.0–33.1) l./min., mean difference 3.7 (range 1.4–6.7) l./min.

Patients with Chronic Chest Disease.—The mean resting ventilation with an oxygen flow of 3 l./min. without re-breathing in 14 patients (see Table) was 8.6 l./min. With re-breathing it was 13.2 l./min. The mean increase was 4.6 (range 0.6–13.6) l./min., or 53%, and was mainly due to an increase in the depth of respiration. Ten patients preferred the period without re-breathing, three detected no difference, and one preferred the period with re-breathing, during which time he appeared to fall asleep. With re-breathing, five patients became greatly distressed and perspired intensely, whereas without re-breathing they were relatively comfortable. The mean change in ventilation between the two periods in these five subjects (5.9 l./min.) was 2 l./min. more than in the remaining subjects. However, the discomfort was unrelated either to the ventilation change or to the pressure fluctuations in the mouthpiece. The latter were slightly less with the re-breathing assembly. This was not unexpected, since, although the total minute-volume was increased by re-breathing, that of the air-mix aperture was reduced on account of the ventilation of the oxygen bag.

The carbon dioxide concentration in the re-breathing bag fluctuated on average between 2.9 and 3.3%, the peak occurring at the end of expiration (average 3.5%). Without re-breathing an average peak concentration of 0.6% carbon dioxide was found. This appears to represent a back leak through the one-way valve of less than 12 ml. of expired air a breath at 26 breaths a minute, which was the average respiratory rate for the subjects, and it is not sufficient to have influenced the experimental findings significantly.

In two subjects, at higher oxygen flows, the carbon dioxide concentration in the bag at the end of expiration fell on the average from 3% to 2% when the oxygen flow was increased from 3 to 6 l./min. and to zero at 9 l./min.

Discussion

The 52% increase in resting ventilation produced by a re-breathing bag in both normal and abnormal subjects is of the same order as that produced in normal subjects by the inspiration of 24% carbon dioxide (Duncan-Weatherley, 1952; Shock and Soley, 1940). During exercise under similar conditions the absolute increase in ventilation is similar, but the proportional increase is much less.

These results confirm the suggestion (Barach, 1940) that re-breathing occurs to an appreciable extent at moderate

Resting Ventilation in 14 Subjects with Chronic Respiratory Failure With and Without Rebreathing (Oxygen Flow, 3 l./min.)

Subject No.	Age	Diagnosis	Resting Ventilation l. min. B.T.P.S.			Resp. Rate	Comments	
			With Rebreathing	No Rebreathing	Difference		Valve	No Valve.
15	61	CB. Emp.	11.7	9.8	1.9	21	Preferred	Perspiring and restless
16	69	CB.	8.5	7.9	0.6	10	"	Breathing " more difficult "
17	63	PMF (D)	23.0	9.4	13.6	34	"	Perspiring; very distressed
18	63	PMF (B)	11.4	8.5	2.9	18	"	
19	63	CB.	6.6	5.7	0.9	8	"	No difference
20	35	CB.	13.6	9.2	4.4	25	Preferred	Perspiring
21	61	CB.	7.5	6.9	0.6	16	"	
22	63	PMF (D)	17.5	10.8	6.7	25	"	" Getting warm "
23	51	PMF (B)	21.1	12.1	9.0	29	"	" Feeling of suffocation "
24	65	CB. PF.	24.2	11.8	12.4	52	"	Both uncomfortable
25	71	CB. Emp.	9.2	7.0	2.2	14	Both uncomfortable	Preferred
26	70	CB.	15.5	8.8	6.7	22	"	No difference
27	36	Emp.	5.0	4.4	0.6	10	"	
28	55	CB.	9.8	7.5	2.3	17	Preferred	" "

CB.=Chronic bronchitis. Emp.=Emphysema (advanced). PF.=Pulmonary fibrosis. PMF (B) or (D)=Category of progressive massive fibrosis of pneumoconiosis.

oxygen flows when oxygen masks of the B.L.B. type are used. The importance of this point, which has been noted by others—for example, Card *et al.* (1940)—may not have been fully appreciated because most masks have been first tested at simulated altitudes in a decompression chamber (Boothby, Lovelace, and Bulbulian, 1938; Kent, 1946; Cotes, 1951; Burns and Hall, 1953) under conditions in which carbon dioxide accumulation is beneficial, or at ground level on normal subjects who are little affected by the increase of ventilation. But subjects with a severe limitation of ventilatory capacity may be made acutely uncomfortable by the increase of ventilation or carbon dioxide retention. These subjects may continue to wear the mask with a small gap at the edge of the facepiece, thus avoiding retention at the cost of inadequate oxygenation of the lungs (E. A. Pask, 1955, personal communication).

Increasing the oxygen flow (Boothby, Mayo, and Lovelace, 1940) is an unsatisfactory remedy, both where economy of oxygen is important, as in domiciliary treatment or with portable equipment, and where there is a risk of accentuating carbon dioxide retention on this account. To achieve oxygen economy a high efficiency mask operating on the oxygen reservoir principle is needed, flows of 2–4 l./min. usually being sufficient. Smaller flows are better for patients with acute exacerbations of chronic lung disease; for these patients 1–3 l./min. has been recommended, either by nasal catheter (Simpson, 1954) or by a mask of the B.L.B. type (Westlake, 1954), but the two methods differ in their efficiency (Fig. 2) and in their liability to carbon dioxide retention, and are therefore not really interchangeable. If a mask which permits rebreathing is to be used in these circumstances it should be modified by the fitting of a check valve into the neck of the bag and used at a reduced oxygen flow. Unmodified masks of this type should be reserved for conditions in which some carbon dioxide inhalation is also desirable.

Summary

The relative efficiency of different types of personal equipment for the therapeutic administration of oxygen is considered. The highest efficiency is achieved by the use of a mask with a reservoir bag for the storage of oxygen during expiration. In one type of mask rebreathing into the bag is permitted; in the other it is prevented by a non-return valve situated at the neck of the bag.

The effect of the design of the oxygen mask upon ventilation has been reassessed during the breathing of oxygen, using a mouthpiece assembly having volume and flow characteristics similar to those of these two types of oxygen mask.

It has been found that for an oxygen flow of 3 l./min. the mean resting ventilation in six normal subjects and in 14 patients with chronic chest disease increased by 52%, from 7.5 to 11.4 and 8.6 to 13.2 l./min. respectively, when the non-return valve at the top of the oxygen reservoir bag was removed. The increase in ventilation is attributable to the rebreathing of expired carbon dioxide, which may also explain the discomfort experienced by some patients when using this type of mask.

It is suggested that masks employing the rebreathing principle should not be used for the administration of oxygen to patients liable to develop acute carbon dioxide retention, or for those with very low maximum ventilatory capacities. Where efficient usage is desirable, masks fitted with a valve at the top of the oxygen reservoir bag to prevent rebreathing are recommended.

We are greatly indebted to Dr. J. C. Gilson (Director, Pneumoconiosis Research Unit) for his advice and helpful criticism; to our colleagues who acted as normal subjects in the investigation; and to Mr. F. Meade for the photography.

REFERENCES

- Barach, A. L. (1940). *Trans. Ass. Amer. Phys.*, **55**, 267.
 — (1948). *Physiologic Therapy in Respiratory Disease*, 2nd ed. Lippincott, Philadelphia.
 Boothby, W. M., Lovelace, W. R., and Bulbulian, A. H. (1938). *Proc. Mayo Clin.*, **13**, 641, 646, 654.
 — and Uihlein, A. (1940). *Ibid.*, **15**, 194.
 — Mayo, C. W., and Lovelace, W. R. (1940). *Trans. Ass. Amer. Phys.*, **55**, 261.
 Burns, T. H. S., and Hall, J. M. (1953). *British Medical Journal*, **2**, 672.
 Campbell, A., and Poulton, E. P. (1935). *Oxygen and Carbon Dioxide Therapy*, Oxford Univ. Press, London.
 Card, W. I., Smith, J. F., Griffiths, W. J., McSwiney, B. A., and Savage, B. (1940). *Lancet*, **1**, 398.
 Christensen, E. M., Urry, A. G., and Cullen, S. C. (1946). *Anesthesiology*, **7**, 399.
 Christie, R. V. (1938). *Lancet*, **2**, 876.
 Cotes, J. E. (1951). Flying Personnel Research Committee Memo 32.
 Davies, H. W., and Gilchrist, A. R. (1925). *Edinb. med. J.*, **32**, 225.
 Donald, K. W. (1949). *Lancet*, **2**, 1056.
 Duncan-Weatherley, A. H. (1952). *Aust. J. exp. Biol. med. Sci.*, **30**, 95.
 Haldane, J. S. (1917). *British Medical Journal*, **1**, 181.
 Hilton, R. (1928). *Ibid.*, **1**, 441.
 Kent, B. S. (1946). *Lancet*, **2**, 380.
 Meakins, J. C. (1920). *British Medical Journal*, **1**, 324.
 — (1921). *J. Path. Bact.*, **24**, 79.
 Poulton, E. P., and Adams, T. W. (1936). *British Medical Journal*, **1**, 567.
 Prime, F. J., and Westlake, E. K. (1954). *Clin. Sci.*, **13**, 321.
 Richards, D. W., jun. (1950). *Bull. N.Y. Acad. Med.*, **26**, 384.
 Shock, N. W., and Soley, M. H. (1940). *Amer. J. Physiol.*, **130**, 777.
 Simpson, T. (1954). *British Medical Journal*, **1**, 297.
 Westlake, E. K. (1954). *Ibid.*, **2**, 1012.

URINE CONCENTRATION AFTER FLUID DEPRIVATION OR PITRESSIN TANNATE IN OIL

BY

R. V. H. JONES, M.B., B.Chir.

Research Assistant

AND

H. E. de WARDENER, M.D., M.R.C.P.

Senior Lecturer in Medicine, University of London

(From the Department of Medicine, St. Thomas's Hospital, London)

It has been demonstrated (Miles *et al.*, 1954) that in convalescent patients with normal renal function the concentration of the urine following dehydration is greater than after an injection of "pitressin" tannate in oil. The present paper confirms that this difference is also present in young healthy subjects, and describes some experiments designed to determine its cause.

Methods.—The observations were made on 49 students, nurses, and doctors carrying out their normal duties both before and during the experimental period; there were 41 men and 8 women, of an average age of 24 years. In all experiments, observations were made on urines collected during the following three periods: (1) 8 a.m.–12 noon, (2) 12 noon–4 p.m., (3) 4 p.m.–8 p.m.; these have been named the morning, afternoon, and evening periods. Urine osmolality was calculated from the freezing point, which was determined with a thermometer incorporated in a bridge circuit (de Wardener and del Greco, 1955).

Experiment 1

A comparison of the effect of 48 hours' dehydration and 5 units of pitressin tannate in oil on urine osmolality, urine flow, and solute output.

This comparison was made on 17 subjects. Fluid deprivation was for 48 hours, beginning at 8 p.m.; during this time all fluids, including soups, ice creams, and fruit, were avoided, but the meals were otherwise normal. Urine was collected during the last twelve hours of this period.

One to two weeks later each subject was given a subcutaneous injection of pitressin tannate in oil at 7 a.m.,